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The Sixth International Conference on
Protection of Materials and Structures from Space Environment

Space & Atmospheric Environments

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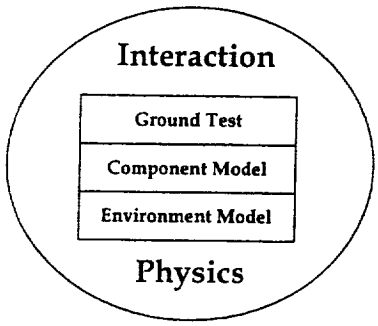
Why Environments & Effects Studies?

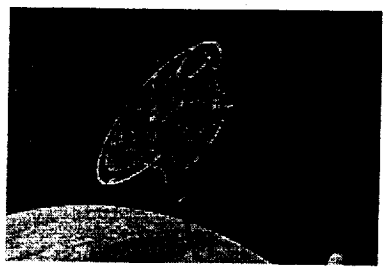
- Space environments are complex.
- Complexity of spacecraft systems is increasing.
- Design accommodation must be realistic.
  - » Need minimum impact on performance
  - » Maintain balance between cost vs. risk
- Environmental problems can be limited at low cost relative to spacecraft cost.

Goal
Use Applied Science Research to Enable Technology Infusion into Space Programs

Performance Predictions

Simulated conditions ⇨ Actual conditions



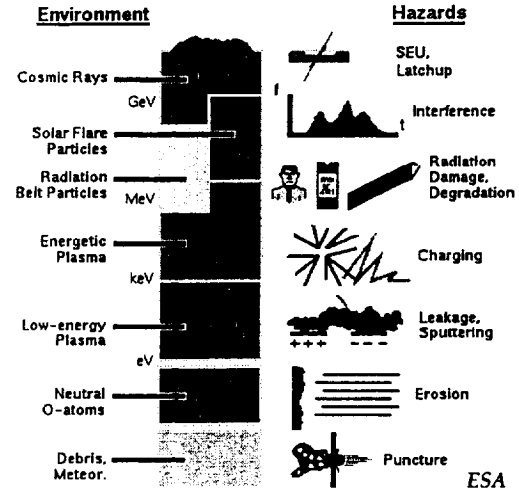


- Accuracy of performance prediction is dependent on fidelity of protocols and models.
- Design margins can drive requirements that preclude use of newer technologies.

Natural Environments

- Atmospheric Density & Composition
- Plasma
- Radiation Environment
- Electromagnetic Radiation
- Meteoroid & *Orbital Debris*
- Thermal Environment
- Geomagnetic Field
- Gravitational Field

Environmental Hazards

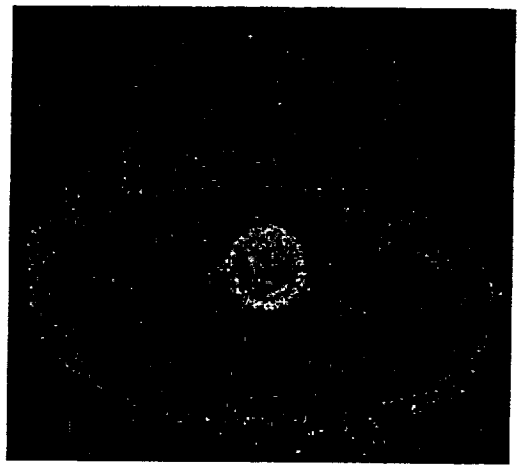


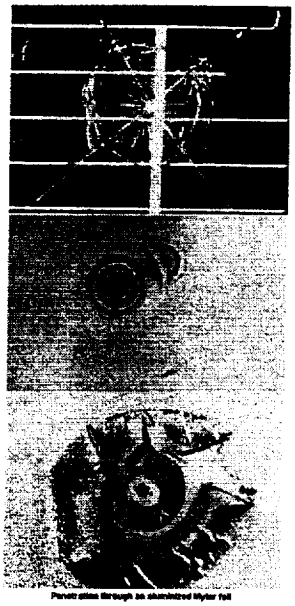
- Low Earth Orbits (LEO)
  - » Low Inclination
  - » Polar
- Middle Earth Orbits (MEO)
- Geostationary (GEO)
- Interplanetary
- Jovian

Meteoroid/Orbital Debris

- Meteoroids
  - » Primarily remnants of comet orbits
  - » Several times a year Earth intersects a comet orbit
  - » Asteriod belt - Sporadic particles on a daily basis
- Debris
  - » Operational payloads, Spent rockets stages, Fragments of rockets and satellites, Other hardware and ejecta
  - » USAF Space Command tracks over 7,000 > 10 cm objects in LEO
  - » Tens of thousands smaller objects

The Threat





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Spacecraft Effects

- Damage and decompression threat
- Hypervelocity impacts from larger particles
- Surface erosion from collisions with smaller objects
  - » Surface effects on thermal, electrical, and optical properties
- Risk Factors
  - » Duration, vehicle size and design, solar cycle, orbit altitude, and inclination
  - » Threat is highly directional

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Neutral Thermosphere

- Definition
  - » Atmospheric Density, Density Variations, Atmospheric Composition (AO), Winds
- Neutral atmospheric constituents
- 90 – 600 km
- Neutral gas particles
  - » Lower - Atomic oxygen (AO)
  - » Higher - Hydrogen & Helium
- Altitude variations due to temperature
  - » Solar cycle effects due to absorption of solar extreme ultraviolet radiation (EUV)
  - » Proxy measurement with 10.7-cm radio flux (F10.7)

Spacecraft Effects

- Spacecraft drag
  - » Density of neutral gas
  - » Altitude decay & torques
- Materials degradation - Erosion
  - » Thermal, mechanical, optical properties
  - » AO (200 – 400 km), Solar cycle dependent
  - » Effects aggravated by micrometeoroid impacts, sputtering, UV exposure, contamination
- Spacecraft glow
  - » Optical emissions generated by excitation of metastable molecules
  - » Surface acts as catalyst – material dependent

Plasma Environment

- Energy < 100 keV - No radiation effects
- Ionized gas where electron and ion densities are approximately equal
- Sources
  - » Ionosphere
    - Electrically charged portion of the atmosphere
    - Low energy (eV)/High Density
  - » Geomagnetic substorm activity
    - High energy (keV)/Low density
  - » Solar Wind
    - Sun's corona
    - Seen at > 10 Billion km from the Sun
- Dramatic variation with altitude, latitude, magnetic field strength, and solar activity

Plasma Interactions – Ionosphere

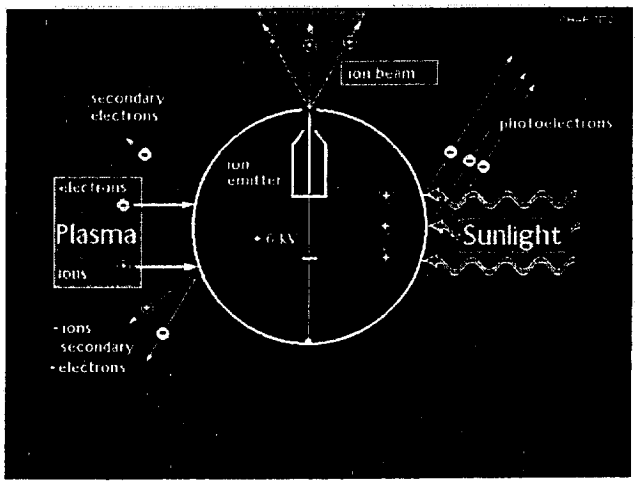
- Supersonic spacecraft motion through background ions in the plasma
- Solar array coupling to plasma
  - » Current drain on solar arrays
- Contamination
  - » Dense pressure of atmosphere in LEO
  - » Modification of ambient atmosphere by outgassing
- Generation and emission of plasma waves
- Polar regions - High level of charging
  - » Exposure to auroral electrons, esp. if current collection occurs in ion-depleted wake zones

Plasma Interactions – Storms

- Induced charge on surface
  - » Disrupt operation of electrically biased instruments
- Missions affected
  - » LEO – Polar orbits
  - » Geosynchronous orbits are generally a greater concern
- Effects
  - » Biasing of instrument readings
  - » Arcing – upsets to electronics, increased current collection, reattractition of contaminants, ion sputtering which leads to acceleration of erosion of materials

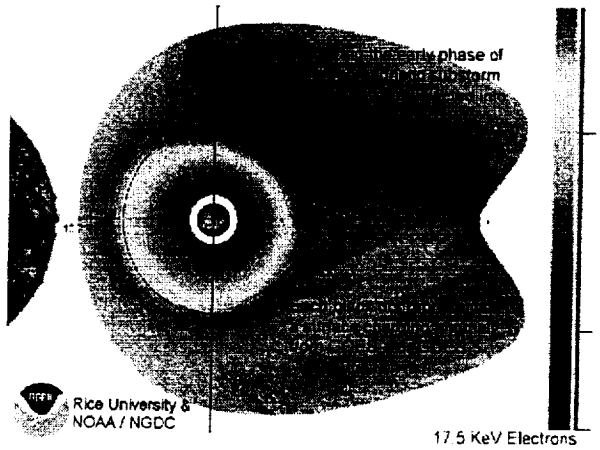
Conditions for Charging

- Large differential
- Large fraction of total flux
- Darkness
- Large spacecraft

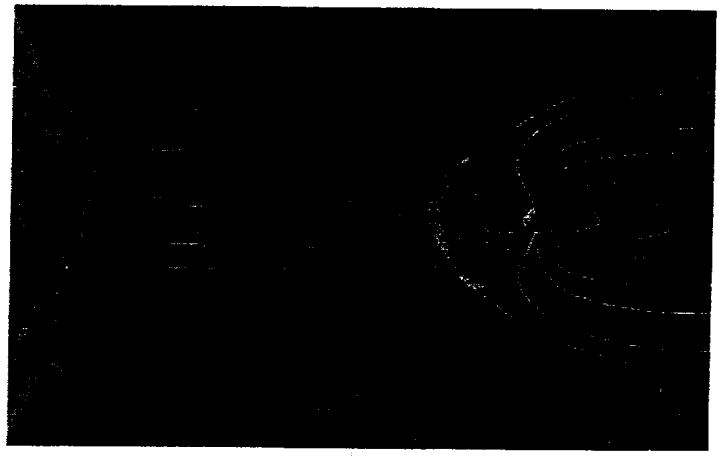


Charging in GEO

- Strong local time effects
- Solar storm effects
- Experience base is in LEO & GEO
  - » MEO?
  - » Auroral regions?



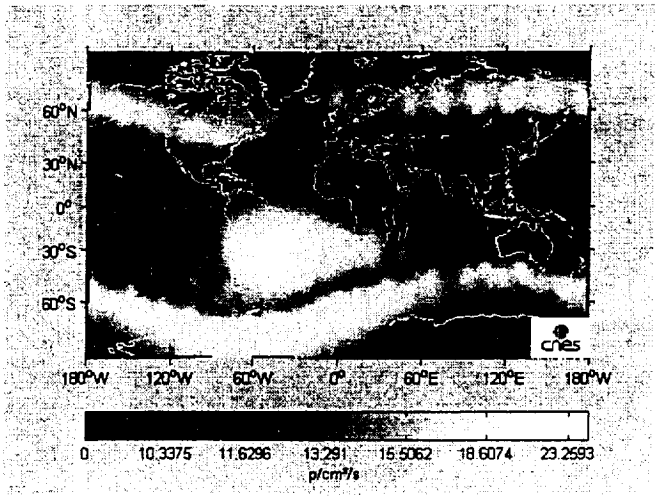
The Radiation Environment



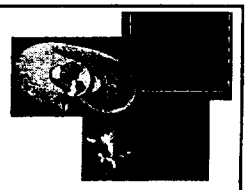
Nikkei Science, Inc. of Japan, by K. Endo

Electron Environment Dynamics

April 2001 Storm



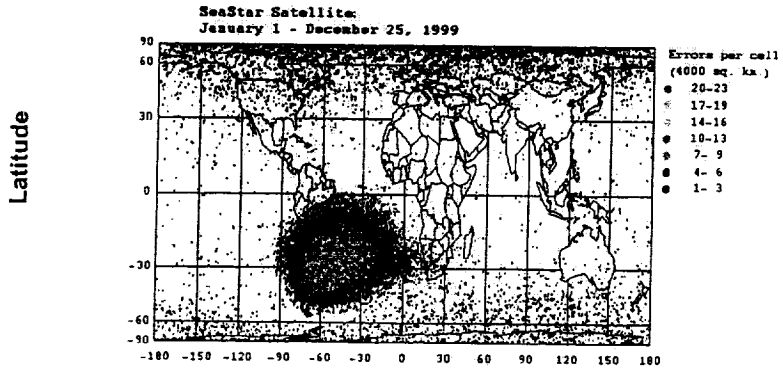
Radiation Effects



- Total Ionizing Dose – Degradation
  - » Materials
  - » Electronics
- Total Non-ionizing Dose – Degradation
  - » Solar Cells
  - » Optocouplers
  - » Optical lens
- Single Event Effects – Single Particle Strikes
  - » Destructive – SEL, SEGR, SEB
  - » Non-destructive – SEU, SET, SEFI,MBU
- Degradation of surface materials
- Deep Dielectric Charging

Seastar- COTS DRAM Technology

Single Event Upsets: January 1 - December 25, 1999 – 705 km



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Definition of Contamination

An unwanted material or substance that causes degradation in the desired function of an instrument or flight hardware

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Systems Affected

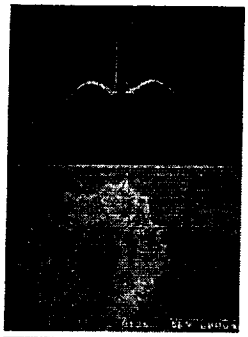
- Optical components - lenses
- Thermal control - external paints & blankets
- Guidance – baffles
- Any sensitive surfaces
  - » Exposed to all environments!

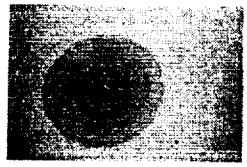
Contamination – Pulling It Together

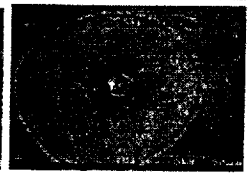
- Micrometeoroids and debris
  - » Surface erosion from collisions with smaller objects
    - Surface effects on thermal, electrical, and optical properties
- Neutral thermosphere
  - » Materials degradation - Erosion
    - Thermal, mechanical, optical properties
    - AO (200 – 400 km), Solar cycle dependent
    - Effects aggravated by micrometeoroid impacts, sputtering, UV exposure, contamination
  - » Spacecraft glow
    - Optical emissions generated by excitation of metastable molecules
    - Surface acts as catalyst – material dependent
- Plasma – Ionosphere
  - » Contamination
    - Dense pressure of atmosphere in LEO
    - Modification of ambient atmosphere by outgassing
- Plasma – Storms
  - » Reattractition of contaminants, ion sputtering which leads to acceleration of erosion of materials
- Non-ionizing and ionizing dose
  - » Degradation of surface materials & optical lenses

Contamination Processes

- Particulates and gases
  - » Outgassing, engine firings, plume impingement, material processes
- Effects
  - » Charging
  - » Glow
  - » False signals on optical detectors
  - » Surface erosion

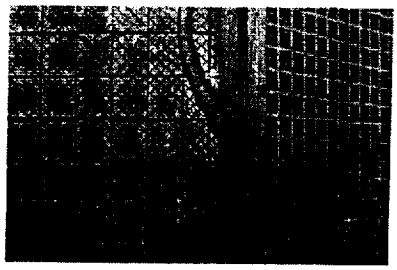






Complexity Increased by Material Processes

- Atomic Erosion
  - » Infrared Radiation
  - » Particle Radiation
  - » Ultraviolet Radiation
  - » Thermal Vacuum Outgassing



Mission Phases for Contamination

- An Issue at All Mission Phases
  - » Construction & Assembly
  - » Ground Handling & Transportation
  - » Launch
  - » Orbital Insertion
  - » Early Outgassing
  - » Long Term Exposure
  - » Recovery

Contamination Risk?

Thermal control surfaces?

H < 1000 km? Instrument calibration?

Solar UV? Baffle design?

Earth albedo UV? Lens design?

UV instruments? Detector design?

IR instruments? Mirror design?

Spacecraft lifetime? Cooled detector systems?

Common Issues

- Many unknowns in space environments & the interaction mechanisms
  - » Model development & validation lags behind technology changes.
  - » Unknowns result in large design margins
    - Higher accommodation/mitigation overheads
    - Can preclude use of newer technologies
- Must be addressed in all design phases
  - » Use a systems approach.
  - » Begin early - "Pay now or pay more later"
- Ground tests cannot duplicate the space environment
  - » Synergistic effects
  - » Enhanced low dose rates